

# From A to Z': Combining Anomaly and Z' Mediation of Supersymmetry Breaking

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**Abstract.** Combining anomaly with  $Z'$  mediation allows us to solve the tachyonic slepton problem of the former and avoid fine tuning in the latter. We describe how the two mechanisms can be combined, and some of the phenomenology of such a joint scenario.

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## INTRODUCTION

$Z'$  mediation of supersymmetry (SUSY) breaking is a mediation mechanism in which both the hidden and the visible sectors are charged under a new  $U(1)'$  gauge interaction. Such a possibility is motivated by the fact that many superstring constructions contain such an “extra”  $U(1)'$  (see references in [1]). This interaction can then mediate SUSY breaking to the visible sector. In this scenario, one assumes that the gauge interaction is unbroken in the hidden sector, and at a scale  $\Lambda_S$  SUSY is broken and a  $Z'$  gaugino mass,  $M_{\tilde{Z}'}$ , is generated. Since all the visible sector chiral superfields are charged under this  $U(1)'$ , the scalars receive a mass at one loop order, while the  $SU(3)_C \times SU(2)_L \times U(1)_Y$  (“MSSM”) gauginos get a mass only at two loop order. As a result, the soft scalar masses are about 1000 times heavier than the gaugino masses. Since direct searches constrain the gaugino masses to be above 100 GeV, we have basically two options.

The first is to assume that the gaugino masses are around 100-1000 GeV. The soft scalar masses are then of the order of 100-1000 TeV and in order to obtain electroweak symmetry breaking at its observed scale, one fine tuning is needed. Such an approach was explored in the original  $Z'$  mediation papers [2]. The second option is to assume that the scalar masses are around 100-1000 GeV. The “MSSM” gauginos are then too light, and they must receive additional contributions from another mediation mechanism, for example anomaly mediation (AMSB) [3].

One can motivate combining anomaly and  $Z'$  mediation in the following heuristic way. For AMSB the soft scalar masses squared can be “so small” that they can actually be negative. For  $Z'$  mediation, on the other hand, they are “too big” compared to the electroweak scale (squared). By combining the two mechanisms we can hope to obtain scalar masses which are “just right”, i.e. of the order of the electroweak scale. Another motivation is that they both naturally arise from an extra dimensional model, as we show in the next section.

In order for such a combined scenario to be viable, we must demand that the AMSB contribution to the soft scalar mass squared, which is roughly  $m_{3/2}^2/(16\pi^2)^2$ , is comparable to the  $Z'$  mediation contribution, which is roughly  $M_{\tilde{Z}'}^2/16\pi^2$ . Here  $m_{3/2}$  is the

gravitino mass. This implies that  $m_{3/2}$  should be about an order of magnitude larger than  $M_{Z'}$ . If such a hierarchy holds, the  $Z'$  contribution to the MSSM gaugino masses is three orders of magnitude suppressed compared to the anomaly contribution and therefore completely negligible. We will now show that such a mild hierarchy is natural within an extra dimensional model.

## “ $Z'$ -GAUGINO MEDIATION”

In the original  $Z'$  mediation papers [2] the mechanism under which the  $Z'$ -gaugino becomes massive was left unspecified. Here we consider a specific implementation that can be thought of as “ $Z'$ -gaugino mediation”. As in the gaugino mediation scenario [4, 5], we assume that SUSY is broken on a spatially separated brane and as a result a gaugino mass term is generated. Unlike the standard gaugino mediation, we assume that *only* the  $Z'$  gaugino mass is generated, while the “MSSM” gauginos remain massless. For example, if we consider one extra dimension, we can have a brane localized term of the form

$$c \int d^2\theta \frac{X}{M_*^2} W_{Z'} W_{Z'} \delta(y-L), \quad (1)$$

where  $W_{Z'}$  is the  $U(1)'$  field strength,  $X$  is the field whose  $F$  component generates the gaugino mass,  $L$  is the size of the extra dimension,  $M_*$  is the 5D Planck mass and  $c$  is a constant. The relation between the 5D and the 4D Planck mass is  $M_*^3 L = M_P^2$ .

When the field  $X$  develops an  $F$  term, a  $Z'$  gaugino mass is generated:

$$M_{Z'} = c \frac{F_X}{M_*^2 L}, \quad (2)$$

where the extra factor of  $L$  arises from different 4D and 5D normalizations. The gravitino mass is of the order

$$m_{3/2} \sim \frac{F}{M_P} = \frac{F}{\sqrt{M_*^3 L}}. \quad (3)$$

If we assume that  $F \sim F_X$  and define  $r \equiv m_{3/2}/M_{Z'}$ , then we should demand that  $M_* L \sim c^2 r^2$ . This product of the 5D Planck mass and the size of the extra dimension is bounded both from above and below. First, to ensure that the gauge coupling are perturbative [4], we need  $M_* L \lesssim 16\pi^2$ . Second, to suppress contact terms of the form

$$\frac{1}{M_*^2} \int d^4\theta Y^\dagger Y Q^\dagger Q, \quad (4)$$

with  $Y(Q)$  hidden (visible) sector fields, which can potentially violate flavor constraints [6], we need  $M_* L \gtrsim 16$ . These two conditions imply that

$$4 \lesssim c r \lesssim 4\pi. \quad (5)$$

With an order one coefficient in equation (1) we can easily generate the appropriate hierarchy. We emphasize that the “ $Z'$ -gaugino mediation” scenario we have presented is a special case of the more general  $Z'$  mediation and the two are not equivalent.

## SPECIFIC IMPLEMENTATION

We now present an explicit implementation of the combined scenario. We choose to do that using the same model for which the original  $Z'$  mediation mechanism was implemented [2]. One interesting feature of this model is that the beta function of the strong coupling vanishes at one loop order. This is not an accident, but a rather general result following from  $SU(3)_C^2 \times U(1)'$  anomaly cancellation condition and very general assumptions [2]. As a result the gluino mass receives non-zero contributions only at two loop order, and for a generic choice of parameters, the gaugino mass hierarchy is  $M_1 > M_3 > M_2$ . This should be compared to the “standard” AMSB for which the gluino is heavier than the bino and the wino.

To show that our model can lead to a reasonable spectrum we choose one specific illustration point. We list the input parameters and the resulting spectrum. The dimensionful input parameters are  $m_{3/2}$ ,  $M_{Z'}$  and  $\Lambda_S$ :

$$m_{3/2} = 80 \text{ TeV}, \quad M_{Z'} = 15 \text{ TeV}, \quad \Lambda_S \sim 10^6 \text{ TeV}. \quad (6)$$

The ratio of the gravitino mass to the  $Z'$ -gaugino mass is within the allowed range of equation (5). The dimensionless input parameters are the  $U(1)'$  charges of  $H_u$  and  $Q$  (the quark doublet), the  $U(1)'$  gauge coupling  $g_{Z'}$ , and the superpotential couplings  $y_t, y_b, y_\tau, y_D, y_E$  and  $\lambda$ . We take

$$\begin{aligned} U(1)' \text{ charges} &: \quad Q_{H_u} = -\frac{2}{5}, \quad Q_Q = -\frac{1}{3} \\ U(1)' \text{ gauge coupling (at } \Lambda_S) &: \quad g_{Z'} = 0.45 \\ \text{Superpotential parameters (at } \Lambda_{EW}) &: \quad \lambda = 0.1, y_D = 0.3, y_E = 0.5, \\ &: \quad y_t = 1, y_b = 0.5, y_\tau = 0.294. \end{aligned} \quad (7)$$

The values of  $y_t, y_b$ , and  $y_\tau$  are chosen to reproduce the values of the top, the bottom, and the tau masses at the electroweak scale.

Running down to the electroweak scale we find the following vacuum parameters:

$$\tan \beta = 29, \quad \langle S \rangle = 11.9 \text{ TeV}. \quad (8)$$

Due to the large  $\tan \beta$  and the large vacuum expectation value (vev) of  $S$ , the vevs are strongly ordered :  $\langle H_d^0 \rangle \ll \langle H_u^0 \rangle \ll \langle S \rangle$ . As a result there is very little mixing in the extended Higgs and neutralino sectors. Here we highlight some of the important details of the spectrum. The full description of the spectrum appears in [7].

- “Higgs” particles **including one loop radiative corrections**

$$m_{h^0} = 0.138 \text{ TeV}, \quad m_{H_1^0} = 2.79 \text{ TeV}, \quad m_{H_2^0} = 4.78 \text{ TeV}$$

- Neutralinos :

$$m_{\tilde{N}_1} = 0.278 \text{ TeV} \text{ (“Wino”)}, \quad m_{\tilde{N}_2} = 0.61 \text{ TeV} \text{ (“Singlino”)}, \quad m_{\tilde{N}_3} = 1.15 \text{ TeV} \text{ (“Bino”)}$$

$$m_{\tilde{N}_4} \sim m_{\tilde{N}_5} \sim 1.2 \text{ TeV} \text{ (“Higgsinos”)}, \quad m_{\tilde{N}_6} = 12.7 \text{ TeV} \text{ (“} Z' \text{gaugino”)}$$

- Charginos

$$m_{\tilde{C}_1} = 0.278 \text{ TeV ("Wino")}, \quad m_{\tilde{C}_2} = 1.2 \text{ TeV ("Higgsino")}$$

- Gluino

$$M_3 = 0.4 \text{ TeV}$$

- $Z'$  gauge boson

$$M_{Z'} = 2.78 \text{ TeV}$$

- MSSM sfermions

$$\text{Lightest : } m_{\tilde{b}_1} \sim m_{\tilde{t}_1} = 0.7 \text{ TeV}, \quad \text{Heaviest : } m_{\tilde{e}_R} \sim m_{\tilde{\mu}_R} = 12.2 \text{ TeV}$$

- Exotic sfermions

$$\text{Lightest : } m_{\tilde{D}_1} = 2.53 \text{ TeV}, \quad \text{Heaviest : } m_{\tilde{E}_2} = 12.8 \text{ TeV}$$

- Exotic fermions

$$m_D = 3.57 \text{ TeV}, \quad m_E = 5.95 \text{ TeV}.$$

## CONCLUSIONS

Combining  $Z'$  and anomaly mediation allows us to avoid fine tuning from the  $Z'$  side, and the tachyonic slepton problem from the anomaly side. It requires a mild mass hierarchy between the gravitino and the  $Z'$  gaugino, which can be obtained from an extra dimensional model. We have presented an explicit implementation, in which unlike “standard” AMSB, the gluino is lighter than the bino. The gauginos, in particular the gluino, are typically lighter than the sfermions. The spectrum also includes a 2.8 TeV  $Z'$ . A more detailed description of this combined scenario will appear in [7].

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